REMOTE SENSING OF EUROPA SURFACE COMPOSITION WITH IONS, NEUTRAL ATOMS, AND X-RAYS IN THE LOCAL SPACE ENVIRONMENT. J. F. Cooper[1], R. E. Johnson[2], and J. H. Waite[3], [1]Raytheon Technical Services Company LLC, SSDOO Project, Code 632, NASA Goddard Space Flight Center, Greenbelt, MD 20771, jfcooper@pop600.gsfc.nasa.gov, [2]Engineering Physics, University of Virginia, Thornton Hall B103, Charlottesville, VA 22904, rej@virginia.edu, [3]Atmospheric, Oceanic and Space Sciences, University of Michigan, 2455 Hayward, Ann Arbor, MI 48109, hunterw@umich.edu.

The surface chemistry of Europa is a mixture of material in unknown proportions from multiple sources: (1) early accretion from the protoplanetary nebula, (2) accretion from comet impacts during heavy and later bombardment, (3) emergence of subsurface (e.g., oceanic, hydrothermal) materials during resurfacing events related to tidal heating, (4) implantation of ions from the magnetospheric plasma, and (5) molecular evolution from radiolysis driven by magnetospheric particle irradiation energy. Observations of the oxygen exosphere and surface trace components including H_2O_2 and CO_2 can easily be attributed to products of magnetospheric interactions with little if any input from Europa's interior. However, whether the observed sulfate hydrates are from endogenic or exogenic sources is related also to the uncertainties about the existence of a liquid water ocean within Europa.

The challenge of future compositional measurements, e.g. by in-situ and remote sensing instruments on the planned Jupiter Icy Moons Orbiter (JIMO), is to separate the intrinsic elemental composition of Europa's surface and subsurface regions from the background components induced by magnetospheric interactions. Remote sensing observations from Earth suggest a net Na source at Europa, based on comparison of Na/K abundance ratios in neutral clouds around Io and Europa, and Na_2SO_4 hydrate is a candidate component for Europa's non-ice materials. Since $MgSO_4$ and H_2SO_4 are also candidates, identification of Europa's non-ice sulfates will require at minimum the separate in-situ and/or remote sensing measurements of abundances for Na, K, Mg, S, and other elemental species in the magnetospheric and surface environments.

Oxygen is of course universally abundant from H_2O ice, but the critical need is to determine ratios for abundances of other species to O. For astrobiology it is crucial to survey magnetospheric and surface abundances of other biogenic elements such as C, N, and P. The ratio Fe/O could provide information on the oxidation state of the putative ocean, for example since this ratio was high in an oxygen-poor ocean like that of the Archean Earth but fell as concentrations of dissolved oxidants increased with the rise of biogenic O_2.

In previous missions from Pioneer to Galileo the in-situ measurement of magnetospheric composition has been marginal even for elemental species, but the potential capabilities of JIMO could extend to measurement of isotopic abundances. Europa presumably accreted from material with standard solar isotopic abundances, but both magnetospheric interactions and biological processes produce isotopic fractionation which could be diagnostic of origin. Elemental species escaping via sputtering from Europa's surface into the local magnetospheric environment, and those found within materials of biological origin, would have preferentially lighter isotopes than for standard solar abundances. Isotopic ratios could serve to measure the age of surface regions, since older regions subject to sputtering should show heavier isotopic fractions than younger regions. Age is also suggested by the emplacement of younger features on older features. Hot spots for biological materials could show unusually low isotopic masses. In either case such regions would become high-priority candidates for landed expeditions to search for molecular evidence of a subsurface ocean and for biochemical signs of life.

A wide variety of instrumental techniques are potentially available to measure Europa surface composition remotely from orbits around Europa and Jupiter, and in-situ on the surface of Europa. The latter would likely provide the highest mass resolution, e.g. for biomolecules and isotopes, but obviously the least information on global distributions. Orbital instruments that directly image sputtered neutrals and x-ray excitation line emission from the surface could provide global geologic context but may have limited mass resolution. On the trailing hemisphere of Europa both the incident fluxes of energetic electrons, and the observed concentrations of sulfates, are higher than elsewhere, so remote imaging of x-ray lines from the irradiated surface materials there might yield compositional data on elemental abundances. Neutral sputtering is driven by keV-to-MeV energetic ions with more global impact distributions on the moon's surface, so low-energy neutral imaging would also cover the leading hemisphere of Europa.

With 2-D/3-D atmospheric and ionospheric models now in development, abundances of neutrals and ions sampled with high mass resolution for elements, isotopes, and molecules by an orbiter in the Europa atmosphere may be correlated to abundances of underlying surface regions. Detectability of heavier molecules could be improved with in-situ sampling at lower altitudes, e.g. for eccentric orbits with periapses at tens of kilometers. A unique capability of JIMO might be to use the Xe ion propulsion beam to create artificially-induced plumes of sputtered material from targeted regions. JIMO cruise measurements of ion and neutral magnetospheric particle composition could also indirectly yield surface composition data, since sputtered neutrals become ionized and are picked up by the corotating magnetospheric field, and a neutral toroidal cloud of alkalis and, likely, hydrogen or oxygen has been observed at Europa's orbit.

Magnetospheric ions originating from the Jovian moons and other sources (interplanetary solar wind, Jupiter's atmosphere) are accelerated to energies of tens of MeV per nucleon and higher during diffusive transport within the Jovian magnetosphere. Instrumental techniques are available to make precise measurements of energy, isotopic mass, and directional distributions for such ions. Phase space density analysis can in some cases be used to trace measured distributions of energetic ions of specific composition (e.g., Na) to points of origin (e.g., Europa). Knowledge that some types of ions, such as Na from Europa and S from Io, originate from discrete sources can in turn be used to investigate the dynamics of ion transport and acceleration in the large-scale magnetosphere. Precision ion spectrometers on JIMO could be used to determine ion charge states from measurements of the anisotropic interactions of high-energy, large-gyroradius ions with moons such as Europa. Since ion gyroradius is inversely proportional to the local magnetic field magnitude, such measurements can also be used to probe induced magnetic fields associated with Europa's putative subsurface ocean and intrinsic magnetic fields as found at Ganymede.

Finally, full characterization of energy and anisotropy distributions for major ion and electron species in the Jovian magnetosphere at the orbits of the icy Galilean moons is required to accurately model the position-dependent yields of magnetospheric irradiation products (neutrals and x-rays) from the moon surfaces. In the case of sputtering at Europa's surface, low energy sulfur and oxygen ions from the Io plasma torus dominate the number density but sputtering yields per unit energy from electronic ionization maximize for these ions at MeV energy. The incident energy distribution also affects the global surface patterns of sputtering, since high energy ions affect larger regions of the moon surface than lower energy ions, the latter having effects more concentrated in the trailing hemisphere like those of energetic electrons.

The energy distributions of incident magnetospheric particles, particularly for more penetrating protons and electrons as compared to short-range iogenic heavy ions, are also important to the resultant density distributions of irradiation products as functions of surface depth on Europa and elsewhere. The relative proportions of products from direct sputtering at sub-micron depths and from volume radiolysis down to meter depths partly determine the altitude distributions of these products in the moon atmosphere. 'Hot' atoms from sputtering initially produce larger scale heights of atmospheric neutrals than 'cold' atoms from leakage of radiolysis products through volume ice at 100 K. Eventually, all atmospheric atoms not reentering, and sticking to, the surface are lost to the magnetosphere due to atmospheric sputtering and dissociation reactions. For radiolytic product measurements it may be preferable to carry out in-situ atmospheric composition measurements of cold (sub-eV) atoms at low altitudes, while neutral imaging samples the hot (~ 10 eV) sputtered atoms at higher altitudes.